ORIGINAL RESEARCH

Muscle Fibre Area, Fibre Type & Capillarization in Male and Female Body Builders

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ABSTRACT

The effects of long-term strength training on skeletal muscle fibre characteristics were evaluated in nine body builders (BB) (five males and four females) and ten control subjects (six females and four males). Muscle fibre area, percentage fibre type, and capillary supply were compared between the BB and controls as well as between the males and females with a two-way analysis of variance design. For the fast-twitch fibre area (FTa), the BB had larger areas than the controls, and males had larger areas than females. The analysis for the slow-twitch fibre areas (STa) showed only a training effect; BB had a larger STa than controls. The FTa in the untrained females and the female BB were similar to their STa; in contrast, both male groups had significantly larger FTa than STa. The BB had significantly more capillaries per fibre than the control groups but the number of capillaries / mm² were similar in all groups. The results suggest that prolonged training in the female BB hypertrophies both the FT and ST fibres. The female BB realized the same increase in capillary per fibre ratio (# cap / f) as the male BB. However, the larger area of the FT fibres compared to the ST fibre seen in both male groups was not observed in either female group.

Key Words: skeletal muscle; capillary supply; maximal voluntary contraction; physical training.

RÉSUMÉ

Les effets d'un programme d'entraînement en force à long terme sur la surface des fibres musculaires ont été évalués à l'aide de l'analyse histochimique qe biopsies musculaires provenant du vaste externe de neuf culturistes (BB) (cinq hommes et quatre femmes) et de dix sujets contrôles (six femmes et quatre hommes). Les résultats de la surface de section, du pourcentage de fibres de type I ou II ainsi que de la capillarisation musculaire ont été comparés entre les deux groupes, à l'aide d'une analyse de variance. La surface des fibres rapide (FTa), semble reliée aussi bien au sexe qu' à la durée de l'entraînement. Les résultats démontrent en effet une surface de section des FTa supérieure chez les BB que chez le groupe contrôle, ainsi que chez les hommes en général, par rapport aux femmes. La surface des fibres lentes (STa) ne semble être fonction que de l'entraînement puisque seuls les sujets BB démontraient des STa supérieures aux valeurs contrôles. La FTa des femmes non-entraînées et des BB était semblable à celle de leur STa. Chez les hommes cependant, des valeurs plus élevées étaient observées pour les FTa que pour les STa. D'une façon générale, les fibres musculaires étaient entourées de plus de capillaires chez le groupe BB que chez le groupe contrôle, bien que le nombre de capillaires / mm² n'était pas différent entre les deux groupes. La torque maximale générée lors de l'extension volontaire d'une jambe à une vitesse de 180 degrés / s et corrigée pour la masse corporelle, n'était pas différente entre les hommes et les femmes BB. Ces valeurs de la torque maximale étaient toutefois supérieures aux valeurs contrôles. Les résultats suggèrent que l'entraînement prolongé en force entraîne chez la femme culturiste une hypertrophie des fibres lentes et rapides. L'augmentation du nombre de capillaires / fibre était similaire chez les BB féminins et masculins. L'hypertrophie relative des fibres rapides par rapport aux fibres lentes observée chez tous les sujets masculins, n'était pas observée chez aucun des sujets féminins, entraînés ou non.

Mots clés: muscle squelettique; débit capillaire, contraction maximale voluntaire; entraînement physique.

Introduction

Muscular strength increases in a similar manner in response to weight training in both males and females (Lewis *et al.*, 1986; Gettman *et al.*, 1982). Both genders experience similar relative increases in absolute strength in response to a given training program, and in most cases the reports of greater initial strength gains in the females can be attributed to their lower strength levels prior to training (Gettman *et al.*, 1982; Hakkinen, 1985; Wilmore *et al.*, 1978). It is not clear, however, whether skeletal muscle fibre

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Table 1
Physical Characteristics of the Body Builders (BB) and Control (C) Subjects

	Males – BB	*Males – C*	*Females – BB*	*Females – C*
Height (cm)	178.0† ± 8.1	174.9† ± 10.0	163.0 ± 2.7	157.3 ± 10.6
Weight (kg)	87.4*† ± 6.8	74.0† ± 7.3	65.2* ± 5.1	58.6 ± 5.0
Age (yrs)	25.6 ± 2.6	23.8 ± 3.5	27.3 ± 4.2	28.5 ± 5.2
Training (yrs)	5.4 ± 2.1		6.3 ± 4.3	
Number	5	4	4	6

* BB significantly < Controls ($p < 0.05$). † Males significantly < Females ($p < 0.05$).
Values are mean ± SD.

morphological adaptations to strength training are also similar in males and females.

Longitudinal training studies and cross-sectional comparisons of different subject groups demonstrate that strength training does not lead to changes in fibre composition in either gender (Costill *et al.*, 1976; Dons *et al.*, 1979; Edstrom and Ekblom, 1972; Nygaard, 1981; Prince *et al.*, 1976; Sale *et al.*, 1987). Some studies (Brown and Wilmore, 1974; Wilmore, 1974) but not all (Cureton *et al.*, 1988) suggest that there is less muscle hypertrophy per unit strength improvement in women compared to men. This has been attributed to the smaller amount of testosterone secreted in females (Brown and Wilmore, 1974; Wilmore, 1974). Studies employing strength-trained male subjects have shown hypertrophy of the fast-twitch (FT) fibres. There are, however, discrepancies as to whether or not a similar degree of hypertrophy occurs in the slow-twitch (ST) fibres. Edstrom and Ekblom (1972) reported selective hpyertrophy in the FT fibres of strength-trained subjects, as did Prince *et al.* (1976). Several other studies showed that FT fibre area hypertrophied more than ST fibres after strength training (MacDougall *et al.*, 1980; Shantz, 1983; Taylor and Wilkinson, 1986). Some studies which have suggested that there are gender-related differences in muscle hypertrophy have used indirect measurements. For example, Brown and Wilmore (1974) and Mathews and Fox (1976) used calculated changes in lean body mass as an indirect measure of muscle hypertrophy. They reported a smaller change in female than in male subjects when both groups were exposed to an identical training program.

The increase in capillary density with endurance training is well established (Andersen, 1975; Brodal *et al.*, 1977; Nygaard, 1981). With regard to the effects of training specifically for body building, male body builders (BB) have a greater number of capillaries around their muscle fibres compared to control subjects (Shantz, 1982; Shantz, 1983; Tesch and Larsson, 1982). Shantz (1983) attributes the stimulus for increased capillarization to the muscle fibre's greater oxygen diffusion distance caused by the hypertrophy. This same fibre hypertrophy, however, causes the density of capillaries to decrease when expressed per unit of muscle cross-sectional area. There are no published data that describe either muscle fibre area or capillary supply for female BB.

The purpose of this study was to compare selected skeletal muscle morphological characteristics, *i.e.*, fibre area, muscle fibre capillarization and fibre type distribution, in both male and female BB with control subjects.

Methods

SUBJECTS

Nineteen young, healthy males and females volunteered for this study. Nine of the subjects, five males and four females, were BB. They had been training specifically for body building over the past two to ten years. Three of the four females had competed in amateur competitions within the past year, but only two of the five male BB had competed as amateurs. The study did not take place in proximity to any competitions; thus all BB were in a post-competition state. The ten control subjects, four males and six females, had no previous strength-training experience. The physical characteristics of the subjects are shown in Table 1. After the experimental protocol was approved by the institutional Human Ethics Committee, all subjects were informed of the purpose of the study, the possible risks and discomforts, the right to withdraw at any time, and writtern informed consent was obtained.

MEASUREMENTS

The percutaneous needle biopsy technique (Bergstrom, 1962) was used to sample muscle tissue from the *vastus lateralis* of the *quadriceps femoris* muscle group. The tissues were mounted in an embedding medium, frozen in ispopentane cooled in liquid nitrogen, and then stored at −70°C until assayed. Serial cross-sections of a 10 μm thickness were cut using an AO Histostat microtome at a temperature of −20°C. The proportion of fast-twitch (FT) and slow-twitch (ST) fibres was determined from histochemical stains for myofibrillar ATPase activity (Brooke and Kaiser, 1970; Doriguzzi *et al.*, 1983). Fibre areas were determined using computerized planimetry of fibres stained for NADH (Novikoff *et al.*, 1961). Twenty-five FT and 25 ST fibres were digitized using a Hewlett-Packard model #85 microcomputer on a model #9111A graphics tablet. Mean fibre area was calculated as follows:

$$(\text{mean ST area} \times \% \text{ ST}) + (\text{mean FT area} \times \% \text{ FT}).$$

Capillaries were visualized with an amylase PAS stain (Andersen, 1975) and photographed. Capillary density (cap / mm²) was expressed as the number of capillaries within a mean area of 191.5 ± 76 mm², in which there were an average of 35 fibres. The number of capillaries on the border of this area was divided by two (Andersen and Henriksson, 1977). The capillary per fibre ratio (#cap / f) was calculated by counting the number of capillaries around the fibres within this area.

Table 2
Muscle Characteristics of Body Builders (BB) and the Control (C) Subjects

	Males – BB	*Males – C*	*Females – BB*	*Females – C*
Mean Fibre area (μm)²	7593*† ± 827	6026† ± 1543	6244* ± 1277	4874 ± 325
Fibre area ST (μm)²	6696* ± 843	4856 ± 1550	5989* ± 1563	4861 ± 511
Fibre area FT (μm)²	8219*† ± 802	6512† ± 1748	6385* ± 1185	5010 ± 571
FTa / STa	1.24† ± 0.15	1.38† ± 0.03	1.09 ± 0.12	1.04 ± 0.18
% Fast Twitch	60.9 ± 11.6	71.3 ± 5.9	58.0 ± 10.2	49.0[a] ± 5.7
#cap / f	2.8* ± 0.4	2.2 ± 0.3	2.3* ± 0.6	1.7 ± 0.5
cap / mm²	212.2 ± 58.2	274.8 ± 65.7	244.6 ± 98.9	236.1 ± 31.5

* BB significantly > Controls ($p < 0.05$).
†Males significantly > Females ($p < 0.05$).
[a]female – C similar to female – BB but significantly < male groups ($p < 0.05$).
Values are mean ± SD.

The peak torque generated during unilateral, maximal voluntary leg extensions at 180° / s was measured using an ARIEL Computerized Exerciser arm-leg unit. The subjects sat strapped into the chair of the unit with the dynamometer lever arm attached to their leg just above the ankle. A detailed description of the dynamometer and the test protocol is published elsewhere (Jacobs and Pope, 1986). The subjects extended their leg with maximal voluntary force through a range of 70 degrees. Peak torque values registered during the movement were used as the strength measure.

Although most athletic performances occur at limb speeds greater than 180° / s (Kanehisa and Miyashita, 1983; Uebel, 1987), BB train at slower velocities to promote muscle hypertrophy (MacDougall *et al.*, 1980; Sale and MacDougall, 1981). For this reason, and in order to facilitate comparisons with other studies that employed a similar velocity, we chose 180° / s as the testing velocity.

STATISTICAL ANALYSIS

A two-factor (gender, training status) analysis of variance (ANOVA) (Dixon *et al.*, 1981) was used to analyze the data. When the *F*-ratio indicated a significant ($p < 0.05$) interaction of gender with training status, then a Duncan Multiple Range test was used to locate significant differences among mean values. In addition a paired *t*-test was used to evaluate the difference between STa and FTa within the male and female groups.

Results

FIBRE AREA

FT fibre area (FTa), ST fibre area (STa) and FTa / STa ratios for the BB and control subjects are shown in Table 2. There were significant main effects of both training status ($p = 0.007$) and gender ($p = 0.018$) on mean fibre area. Trained individuals had larger mean fibre areas than controls and males had larger mean fibre areas than females. There were also main effects of training status ($p = 0.008$) and gender (0.005) on the FTa. Thus the BB had larger FTa than controls, and the males had larger FTa than the females. The analysis of the STa showed only a main effect of training status ($p = 0.012$); the BB had larger STa compared to the control group. The FTa / STa ratio showed a main effect of gender ($p = 0.014$); males had larger ratios than females. Similarly, when the difference in area between the ST and FT fibres was analysed, there was a main effect of gender; the male difference was significantly larger than that of the females. A paired *t*-test was then used to determine if the FT fibres were significantly larger than the ST within each gender grouping. The analysis for the males revealed that the FTa was significantly larger than the STa ($p = 0.001$); the female FTa was not different from the STa ($p = 0.273$).

FIBRE TYPE DISTRIBUTION

The proportion of FT fibres is shown in Table 2. The ANOVA showed that there was a significant interaction of gender with training status when the fibre type distribution was compared. The *post hoc* comparisons showed that the female controls had similar %FT fibres as the female BB, but significantly less %FT fibres compared to the male BB and male controls ($p < 0.05$).

CAPILLARY SUPPLY

The #cap / f and the cap / mm² are shown in Table 2. The ANOVA showed only a main effect only for training status. The #cap / f was significantly greater for the BB compared to the controls ($p = 0.015$). The analysis of the cap / mm² showed neither training status ($p = 0.375$) nor gender ($p = 0.918$) differences.

PEAK TORQUE

The absolute and relative (per kg body weight) peak torque generated during the maximal leg extensions are shown in Table 3. There were significant main effects of both gender and training status on absolute peak torque. It was greater in the BB than in the controls ($p < 0.001$) and greater in males than females ($p < 0.001$). When expressed per kg body weight, the relative peak torque was greater in the BB than in the controls ($p = 0.004$). There was no gender difference ($p < 0.136$).

Discussion

The present study confirms previous reports of a pronounced specific hypertrophy of the FT fibres in males as well as a general hypertrophy of both main fibre types with strength training (Alway *et al.*, 1988; MacDougall *et al.*, 1984; Sale and MacDougall,

Table 3
Peak Torque during Maximal Voluntary Unilateral Leg Extension at 180°/s in Body Builders (BB) and Control (C) Subjects

	Males – BB	*Males – C*	*Females – BB*	*Females – C*
Absolute				
peak torque 180°/s (N·m)	191.2*† ± 21.7	151.9† ± 28.1	145.5* ± 8.3	97.2 ± 11.9
Relative				
peak torque / body mass (N·m/kg)	2.2* ± 0.2	2.0 ± 0.3	2.2* ± 0.2	1.8 ± 0.2

*BB > Controls ($p < 0.05$).
†Males > Females ($p < 0.05$).
Values are mean ± SD.

1982; Shantz *et al.*, 1983; Tesch *et al.*, 1984). Indeed Shantz (1982) and Shantz *et al.*, (1983) showed that elite male BB had a mean FTa of over 10 000 μm^2 while their STa were 6800 μm^2. Although both fibre type areas in their BB were larger when compared to their male controls, both male groups showed selective hypertrophy of the FT fibres. Their female subjects did not show this selective hypertrophy. In fact there was no difference between their STa and FTa. This is similar to our female data.

The smaller muscle fibre size measured in our female BB is consistent with the speculation that females who undergo strength training programs will not exhibit the same degree of muscle hypertrophy as occurs in males (Brown and Wilmore, 1974; Wilmore, 1974). For example, one of our subjects was the Canadian Amateur Heavy Weight Class Champion female body builder of 1987. She had been training for ten years. Her weight during this experiment was 70.7 kg, but at the time of her championship she weighed 61.1 kg. She had the biggest FTa and STa of all the female subjects. Her STa and FTa were 7880 and 7920 μm^2, respectively. Her STa value was greater than the mean STa value for the male BB but her FTa value was less that the mean FTa value for the male BB. She did not show the difference in FTa and STa that occurred in our male subjects. Thus the smaller visual hypertrophy observed in female BB compared to male BB may be related to the FT fibres. This speculation is consistent with the report of Costill *et al.* (1976), who in describing muscle fibre characteristics of a group of international male and female track athletes, reported that their female middle-distance runners and long jumpers appeared to have similar STa but smaller FTa compared to their male counterparts. Differences in muscle cross-sectional area can also be due to the total number of fibres within a muscle. Sale *et al.* (1987) reported fewer muscle fibres in the biceps brachii of female subjects compared to males. If this difference in fibre number also occurs in other muscles of the body then it could account for some of the visual differences in hypertrophy observed in male and female body builders.

The STa and FTa of our control group of males were similar to other studies where active controls were used, *i.e.*, FTa were greater than STa (MacDougall *et al.*, 1982; Shantz, 1983; Tesch and Larsson, 1982). The STa and FTa of our female active control subjects were similar, in accordance with the reports of Shantz *et al.* (1983) and Nygaard (1981) who also used active controls. These results differ, however, from other studies of female sedentary control groups which report greater STa than FTa (Aniansson *et al.*, 1980; Costill *et al.*, 1976; Nygaard, 1981). Interestingly, smaller FTa than STa have also been reported for female endurance-trained athletes (Costill *et al.*, 1976; Costill *et al.*, 1987; Gregor *et al.*, 1979; Nygaard, 1981).

The greater absolute strength of our BB compared to our control subjects, and our males compared to the females, is consistent with earlier reports (Bell and Jacobs, 1986; Maughan, 1984; Sale and MacDougall, 1982; Sale *et al.*, 1987; Shantz *et al.*, 1983; Tesch and Larsson, 1982). When strength was expressed per kilogram of body weight the body builders were still stronger than the controls, but the gender difference disappeared.

Muscle fibre type distributions in our male BB and male control subjects were similar and were not markedly different from those reported previously for weight-lifters or body builders (Gollnick *et al.*, 1972; MacDougall *et al.*, 1982; Tesch and Larsson, 1982). Our female BB and female control subjects had similar %FT fibres and their values were similar to those reported in the literature (Costill *et al.*, 1976; Nygaard, 1981).

The absolute values for the cap / mm^2 for our male BB and male controls agree with others studies where controls and either body builders or weight lifters were used (Shantz, 1982; Shantz, 1983; Tesch *et al.*, 1984). Our #cap / f for the male BB and male controls agree with the work of Shantz (1982) who looked at BB, rowers, untrained and endurance trained subjects.

We could find no published capillarization data for female BB for comparative purposes. Our female control group values for #cap / f and cap / mm^2 were, however, similar to those of Aniansson *et al.* (1980) and Nygaard (1981).

The #cap / f was greater in the BB, 2.6 *vs* 1.9, compared to the controls. This confirms several studies which show that endurance and strength training can increase the #cap / f (Andersen and Henriksson, 1977; Brodal *et al.*, 1977; Costill *et al.*, 1987; Inger, 1979; Nygaard, 1981; Shantz, 1982; Tesch *et al.*, 1984).

The interpretation of our results was obviously confounded by the fact that this is a descriptive study of a cross-sectional nature. There was no control over the prior training history of our subjects. Thus, it is possible that the male BB trained differently than the female BB and any difference that occurred between the two groups may have been the result of the unknown training history.

In summary, several studies have described skeletal muscle adaptations to endurance and strength training in male subjects. The present study was undertaken in an attempt to address the paucity of information available regarding the effects of long-term strength training, in the form of body building, on female skeletal muscle. The present results demonstrated that the FTa and STa of the female BB increased to the same extent. This was similar to the hypertrophy that occurs in the ST fibres of the male BB. The FTa of the female BB, however, were not as large as the FTa of the male BB. In addition the female BB did not show the same size difference between the FT and ST fibres that occurred for the male BB. This difference in size between the FT and ST fibres in the male BB, however, may be more gender-than training-related, because the male control subjects also showed this selective hypertrophy of the FT fibres. Finally, in association with the smaller fibre areas observed in the female BB, the #cap/f tended to be reduced compared to the male BB.

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